A New Atmospheric Motion Vector Intercomparison Study

David Santek[1], Javier García-Pereda[2], Chris Velden[1], Iliana Genkova[3], Dave Stettner[1], Steve Wanzong[1], Sharon Nebuda[1], Max Mindock[1]

[1] CIMSS/UW-Madison, 1225 W. Dayton St., Madison, Wisconsin, 53706 USA
[2] NWCSAF/AEMET, Leonardo Prieto Castro 8, Madrid, 28040 Spain
[3] IMSG/NOAA/NCEP, 5830 University Research Court, College Park, Maryland, 20740 USA

Abstract

This study furthers a line of previously completed research regarding the similarities and differences between the operational Atmospheric Motion Vector (AMV) algorithms of various satellite-derived wind producers. By using a common set of MSG/SEVIRI images and ancillary data, past intercomparison studies assessed how the cloudy AMVs from each unique wind producer compared in terms of coverage, speed, direction, and cloud height (Genkova et al. 2008; Genkova et al. 2010).

The current study focuses on including the CMA and NWC SAF AMV algorithms in the intercomparison in order to quantify its performance relative to other AMV algorithms, on updating the results of the previous AMV intercomparison studies due to the changes that have occurred since 2009, and lastly, on performing follow up studies, identified in the previous intercomparison work, to analyze particular issues in pursuance of a more complete understanding of how the different AMV algorithms compare.

The study finds a mix of both positive and negative results. The different AMV algorithms successfully determine the horizontal and vertical displacements of the moved features, but not all centers define a consistent AMV speed and direction with these displacements. Using the IR brightness temperature (T_{BT}) for the height assignment, the distribution of AMV heights is highly variable due to the variability of how this representative T_{BT} is defined. When additional height assignment techniques are used, all centers except JMA improve the AMV validation statistics. Nevertheless, the improvement is limited for some of the centers because of using the improved height assignment techniques in only a small part of the data. The two centers using CCC height assignment method (EUM and NWC) are in general the ones obtaining the best validation statistics. Considering the AMV coverage, important differences occur between centers even in the case where a similar prescribed configuration is used.

This paper is a summary of the full AMV intercomparison Technical Report which can be found at: www.nwcsaf.org/HD/files/vsadoc/CIMSS_AMV_Comparison_FinalReport_04July2014.pdf.

INTRODUCTION

The first Atmospheric Motion Vector (AMV) algorithm intercomparison study analyzed data from five centers across the world. Since then, AMV algorithms have changed and the AMV algorithms for CMA and NWC SAF had yet to be compared to any of the other wind producers. So, this report not only includes these two new AMV algorithms, but it also updates and expands on the previous studies.

The report analyzes the AMV algorithms for the following wind producers. The three-letter abbreviations are used throughout the remainder of this report.

- BRZ: Brazil Weather Forecast and Climatic Studies Center
- CMA: China Meteorological Administration
- EUM: EUMETSAT (European Organization for the Exploitation of Meteorological Satellites)
- JMA: Japan Meteorological Agency
- KMA: Korea Meteorological Administration
- NOA: National Oceanic and Atmospheric Administration
- NWC: NWC SAF (Satellite Application Facility on Support to Nowcasting & Very Short Range Forecasting)

Output provided by each of the wind producers is analyzed in four independent experiments, each one designed to measure differences related to a specific aspect of the AMV algorithms. Portions of the scripts used were first developed in the previous intercomparison study, which therefore allows for comparisons to be made between the studies (Genkova et al. 2008, 2010).

The AMV output originated from each algorithm's analysis of a triplet of infrared (10.8µ) Meteosat–9, full–disk images from 17 September 2012 at 1200, 1215, 1230 UTC, one of which is shown in *Figure 1*. Additionally, both 6.2µ, 7.3µ, 12.0µ and 13.4µ images and Meteorological Products Extraction Facility (MPEF) output products "Scene Type and Quality" and "Cloud Analysis" for the same slots were provided, in case AMV producers wanted to use them for the AMV height assignment procedure in Experiment 4.

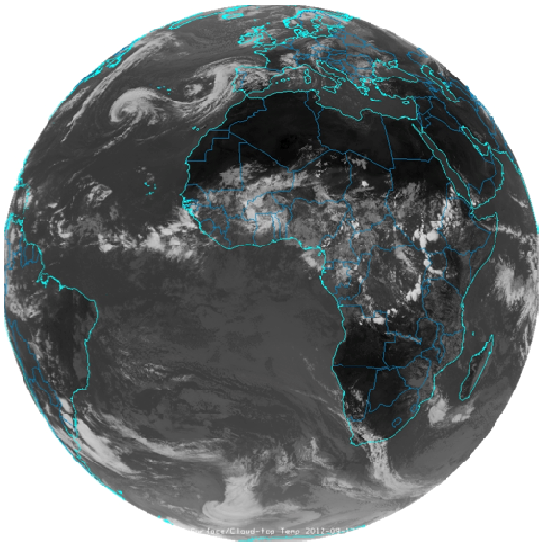


Figure 1: **Meteosat-9 10.8 µm from 17 September 2012 at 1215 UTC**

ECMWF forecast grids for the 12- and 18-hour forecast from the 17 September 2012 0000 UTC run were provided as ancillary data. They were reformatted to the Meteosat–9 domain with the following specifications:

- 135x135 grid centered at 0°N/0°E
- Domain: 67°S to 67°N; 67°E to 67°W
- 1° spatial resolution
- 40 vertical levels
- Parameters: pressure, geopotential height, temperature, water vapor mixing ratio, ozone mixing ratio, wind speed, wind direction, and dew point temperature.

Note: The NOAA AMV processing software requires additional parameters, so additional NWP background data were used.

Each center's output for the experiments included data for identical variables (*Table 1*), with three exceptions:

- BRZ did not report QI with forecast (QIWF)
- CMA did not report QI without forecast (QINF)
- JMA did not report AMV speed for Experiment 1.

The description and configuration of the individual wind retrieval algorithm is extracted from information provided by each producer in response to a questionnaire. A summary is found in *Section 6: Summary of Wind Retrieval Algorithms* of the full report.

In this new Intercomparison study, an additional analysis is performed with the goal to quantify the differences in terms of statistical significance. This is done by using a paired t-test. Paired t-tests, unlike the standard (Student's) t-test, assume two data points are related before it determines if they are statistically different. In our case, each data point from center X is paired, by having both latitude and longitude coordinates within a specified distance, with its corresponding data point from center Y.

For each of the comparisons between AMV wind producers, paired t-tests are calculated for several variables in each experiment (horizontal and vertical displacement, speed, direction, pressure, quality indicator with and without forecast) in order to compare every combination of centers, with a 95% confidence setting.

Parameter	Code	Description
1	IDN	Identification number
2	LAT[DEG]	Latitude
3	LON[DEG]	Longitude
4	TBOX[PIX]	Target box size
5	SBOX[PIX]	Search box size
6	SPD[MPS]	AMV speed
7	DIR[DEG]	AMV direction
8	P[HPA]	AMV pressure
9	LOWL	Low level correction
10	GSPD[MPS]	Background guess wind speed
11	GDIR[DEG]	Background guess wind direction
12	ALB[%]	Albedo
13	CORR[%]	Correlation
14	TMET	Brightness temperature
15	PERR[HPA]	AMV pressure error
16	HMET	Height assignment method
17	QINF[%]	QI without forecast
18	QIF[%]	QI with forecast
19	HDISP1	Horizontal pixel displacement for first pair
20	VDISP1	Vertical pixel displacement for first pair
21	HDISP2	Horizontal pixel displacement for second pair
22	VDISP2	Vertical pixel displacement for second pair

***Table 1:* Reported Variables**

EXPERIMENTS

Four experiments were designed to test and compare different aspects of the AMV algorithms: target selection, tracking, cloud height assignment, and quality control.

Experiment 1

The winds producers extracted AMVs from images with a known displacement (four columns left and two lines down for the second one with respect to the first one, and the third one with respect to the second one). This allows this experiment to test the tracking step in each AMV algorithm. Because each one of the three images is identical, the pattern matching code in each algorithm should work perfectly. For collocated targets, these "artificial AMVs" are analyzed to quantify differences in the tracking process, considering the pixel displacement distribution, speed and direction distribution, and collocation differences.

There are two main positive results from Experiment 1:

- All AMV algorithms detect the shift correctly, generally with no more than a 0.1-pixel difference (related to the use of subpixel tracking implemented by each center).
- When using a distance threshold of 35 km, resulting in 10867 collocated vectors, neither the horizontal nor vertical displacement differences between any two centers are statistically significant. However, there are numerous couplings of centers for both speed and direction that result in statistically different displacements.

Considering this, BRZ and CMA appear to have an AMV speed dependence on distance from the satellite subpoint, which may have been due to the method used to compute the feature displacement (BRZ) or to a truncation in the speed (CMA).

Experiment 2

The producers extracted AMVs with their standard algorithm configuration, while only using the MSG/SEVIRI IR10.8µ images and the ECMWF model data for the height assignment. Each AMV producer's standard algorithm is defined by the settings (target scene size, search scene size, etc.) it typically uses. In addition, a best-fit analysis is utilized in order to further investigate differences in cloud heights.

By allowing each AMV producer to use their typical settings, this experiment tests the target selection and tracking steps in each algorithm. The differences have been examined through the parameter distributions, collocation plots, rawinsonde comparisons, model grid comparisons, and best fit height comparisons.

Surprisingly, despite each algorithm only using the IR brightness temperature (T_{BT}), the bulk distribution of AMV heights is highly variable, and when paired, each combination of two centers has a statistically significant difference, with most differences ranging from 30 to 80 hPa from each other; the largest differences occurring with the different centers compared to EUM (up to 130 hPa). This indicates the variability is likely due to how the representative T_{BT} is determined. Regarding the wind speed, EUM compared to NWC and JMA result in the only two cases not being statistically different. NWC and EUM is additionally the only combination very close in terms of both speed and direction, despite having a cloud height bias of 130 hPa. The average speed difference across all centers ranges from 0.3 to 1.0 ms^{-1}.

When the AMVs are compared to rawinsondes (*Table 2*) or to the NWP background (*Table 3*), NWC has the lowest errors (vector RMS of 6 and 5 ms^{-1} respectively), while BRZ and EUM have the highest (vector RMS of 9 ms^{-1}). Regarding EUM, the presence of upper-level winds being too low and lower-level winds being too high, the large differences of heights compared to other centers, and the large errors compared to rawinsondes suggest the IR brightness temperature height assignment did not perform well.

Considering the comparison of collocated AMVs (shown in the full report), there are not significant changes in the validation statistics. NWC, JMA and KMA show the best results while EUM shows again the worst results.

	N	Pre Bias	Pre RMS	Spd Bias	Spd RMS	Dir Bias	Vec RMS
BRZ	63	0.67	18.81	0.14	5.27	-11.12	9.59
CMA	241	3.60	26,33	0.17	7.51	5.05	8.99
EUM	268	-0.53	26.57	3.09	7.24	0.05	9.43
JMA	177	-2.20	26.26	0.36	6.04	6.07	8.04
KMA	1346	1.19	24.98	-0.02	5.94	9.04	7.91
NOA	361	-1.59	27.14	3.08	6.30	12.84	8.94
NWC	2410	-1.86	26.03	-0.78	4.75	1.53	6.14

Table 2: **Experiment 2: AMV comparison (QI without forecast >= 50; for CMA QI with forecast >=50) to rawinsondes winds within 150 km. N = number of matches; Pre Bias = pressure bias; Pre RMS = pressure RMS; Spd Bias = wind speed bias; Spd RMS = wind speed RMS; Dir Bias = wind direction bias; Vec RMS = vector RMS. The extreme for each category is highlighted: Yellow = high value; cyan = low value**

	N	Vec Diff	Vec RMS
BRZ	743	7.51	8.89
CMA	3964	7.07	8.22
EUM	5378	6.88	9.73
JMA	3498	4.50	6.05
KMA	26427	5.95	7.88
NOA	8180	6.87	8.79
NWC	43626	4.76	5.68

Table 3: **Experiment 2: AMV comparison to NWP background. N = number of matches; Vec Diff = mean vector difference; Vec RMS = vector RMS. The extreme for each category is highlighted: Yellow = high value; cyan = low value**

Experiment 3

The producers extracted AMVs with a prescribed algorithm configuration, while again using the MSG/SEVIRI IR10.8µ images and the ECMWF model data for the height assignment. The prescribed algorithm defined several parameters, such as the target scene size and the search scene size.

The prescribed AMV configuration allows for differences in the tracking and quality control steps to be highlighted, due to the target selection parameters being set constant across AMV producers. Identically to Experiment 2, the differences are examined through parameter distributions, collocation plots, rawinsonde comparisons, model grid comparisons, and best fit height comparisons.

The results are very similar to Experiment 2, since the height assignment options are restricted to IR brightness temperature. There are less collocated vectors (only 370 as opposed to 7050 in Experiment 2) due to the lower overall number of AMVs when the prescribed target and search box size are used. Considering this, there are substantially fewer statistical differences between centers in speed and direction (in fact, differences between all centers for direction are not statistically significant), although pressure and QI values are still largely statistically different.

Experiment 4

The winds producers extracted AMVs with the same prescribed algorithm configuration as in Experiment 3, but now using the height assignment method of their choosing (e.g., CO_2 Slicing, H_2O Intercept, CCC method with the use of an external cloud product, etc.). A verification to determine if the new AMV heights improve the statistics over the results from Experiment 3 is also included.

The usage of the prescribed AMV configuration paired with varying height assignment methods spotlights the differences in the height assignment and quality control steps. The improved height assignment methods result in a shift in the distribution of AMV pressure, for both upper and lower level clouds, especially noted for EUM AMVs (whose vector RMS improves from 9-10 to 5-6 ms^{-1}), NOA (from 8 to 7 ms^{-1}), and NWC (from 5-6 to 4 ms^{-1}), as shown in *Table 4* and *Table 5*.
Other centers (BRZ, CMA, KMA, JMA) have very few AMVs shifted in height, resulting in a smaller change in the comparison errors against rawinsonde and model grid winds. In any case, the impact of the additional height assignment methods is positive in all cases except for JMA, for which statistics degrade in Experiment 4 respect to Experiment 3.

	N	Pre Bias	Pre RMS	Spd Bias	Spd RMS	Dir Bias	Vec RMS
BRZ	153	0.63	9.77	0.55	5.61	-3.07	10.05
CMA	237	-1.11	18.58	-1.30	6.40	5.28	7.74
EUM	307	0.22	22.87	-0.61	4.73	1.99	6.07
JMA	154	-3.00	21.50	-2.26	7.64	8.89	9.60
KMA	326	-0.63	21.91	-0.73	4.72	2.68	6.38
NOA	131	0.35	22.75	1.48	5.79	9.01	7.70
NWC	73	-0.76	17.53	-0.60	3.48	-3.74	4.67

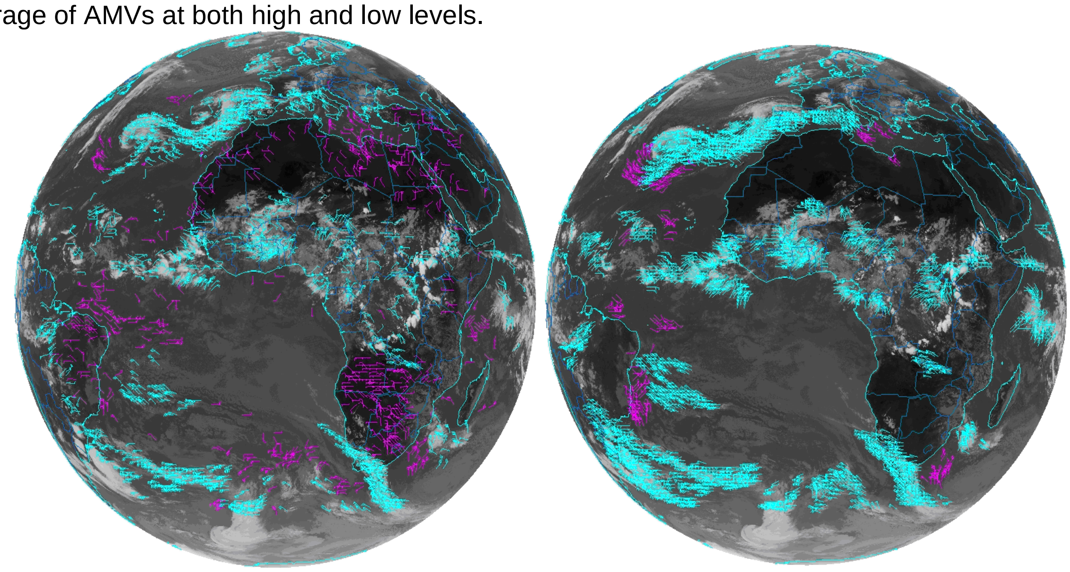
Table 4: **Experiment 4: AMV comparison (QI without forecast >= 50; for CMA QI with forecast >=50) to rawinsondes winds within 150 km. N = number of matches; Pre Bias = pressure bias; Pre RMS = pressure RMS; Spd Bias = wind speed bias; Spd RMS = wind speed RMS; Dir Bias = wind direction bias; Vec RMS = vector RMS. The extreme for each category is highlighted: Yellow = high value; cyan = low value**

	N	Vec Diff	Vec RMS
BRZ	1590	8.02	9.67
CMA	4743	6.38	7.44
EUM	6583	3.91	5.36
JMA	3514	4.91	6.59
KMA	4574	5.16	6.83
NOA	2274	5.90	7.54
NWC	1419	3.05	4.01

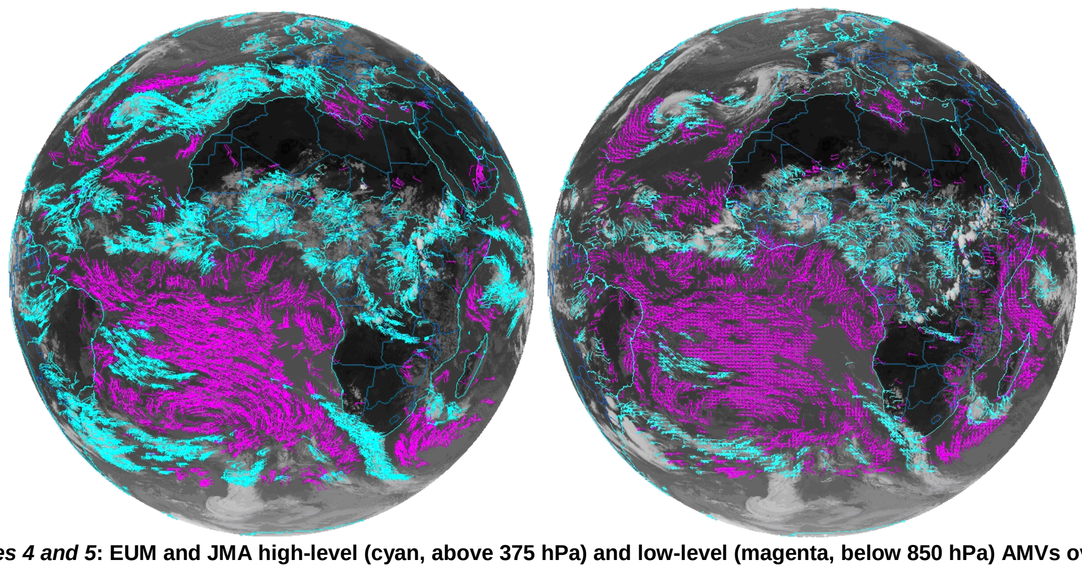
Table 5: **Experiment 4: AMV comparison to NWP background. N = number of matches; Vec Diff = mean vector difference; Vec RMS = vector RMS. The extreme for each category is highlighted: Yellow = high value; cyan = low value**

Considering the collocated vectors (numbering 9942), nearly all speed, direction, pressure and QI differences are significant between all centers. Pressure differences are smaller than in Experiment 3, although the mean difference for collocated vectors has still a range between 20 and 100 hPa. In the corresponding statistics against rawinsonde and NWP background winds (shown in the full report), BRZ has the largest vector RMS values while EUM and NWC show the smallest ones, so showing the similarities provided by their common height assignment method (CCC method).

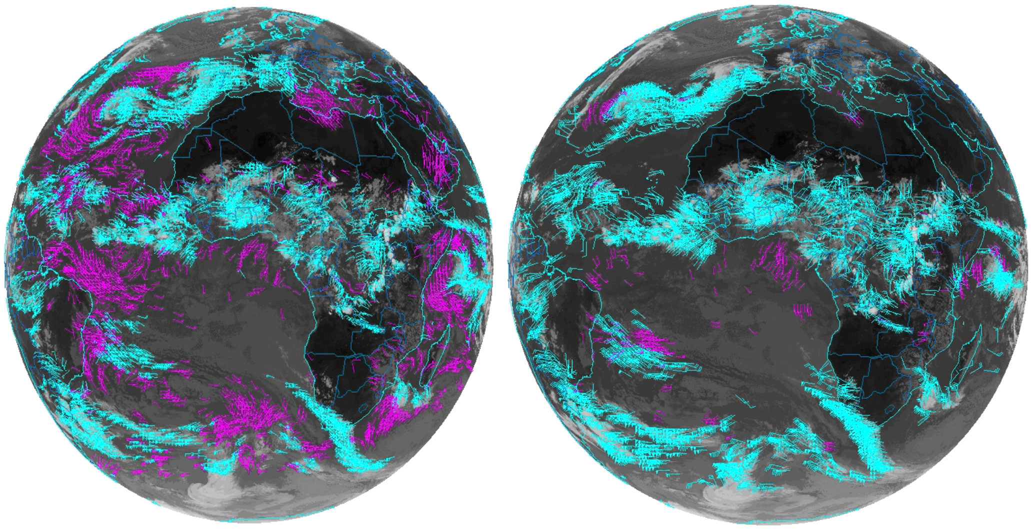
The distribution of AMV vectors for Experiment 4 for the different centers, considering high level winds (above 375 hPa) and low level winds (below 850 hPa) is shown in *Figure 2* to *Figure 8*. The coverage of EUM AMVs is the most complete; the density of winds in the two mid-latitude cyclones to the northwest of Africa and in the marine stratus in the Southern Ocean is especially to be noted.
The coverage of BRZ, CMA, NOA and KMA algorithms is good for the high level clouds; however few low level vectors are detected over the Southern Ocean (in general caused by the AMV level being defined as higher than 850 hPa). Instead, for the JMA algorithm the coverage of low level winds is similar to EUM while the coverage at high levels is not as complete.
Finally, the NWC algorithm captures both high and low level winds, although the density of data is smaller to EUM using the prescribed configuration (equivalent to EUM operational configuration). If the NWC operational configuration is used (shown in *Figure 9*), it results in a very high resolution coverage of AMVs at both high and low levels.



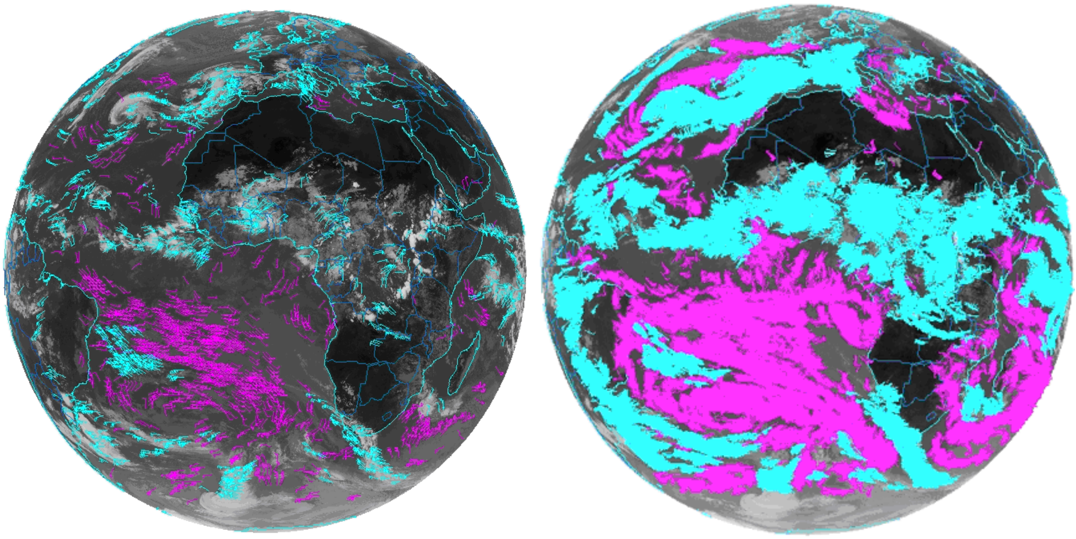
***Figures 2 and 3*: BRZ and CMA high-level (cyan, above 375 hPa) and low-level (magenta, below 850 hPa) AMVs overlaid on the Meteosat-9 10.8µ from 17 September 2012 at 1215 UTC**



***Figures 4 and 5*: EUM and JMA high-level (cyan, above 375 hPa) and low-level (magenta, below 850 hPa) AMVs overlaid on the Meteosat-9 10.8µ from 17 September 2012 at 1215 UTC**



***Figures 6 and 7*: KMA and NOA high-level (cyan, above 375 hPa) and low-level (magenta, below 850 hPa) AMVs overlaid on the Meteosat-9 10.8μ from 17 September 2012 at 1215 UTC**



***Figures 8 and 9*: NWC high-level (cyan, above 375 hPa) and low-level (magenta, below 850 hPa) AMVs, using the prescribed and the NWC operational configuration respectively, overlaid on the Meteosat-9 10.8μ from 17 September 2012 at 1215 UTC**

CONCLUSIONS

Brazil Weather Forecast and Climatic Studies Center

Results from Experiment 1 indicate an error in determining wind speeds up to 10 ms^{-1}, depending on the distance from the satellite subpoint. However, the best-fit analyses suggest there are still good AMVs in this dataset, as the best-fit adjustment and the corresponding improvement in statistics compared to the background is similar to other centers.

China Meteorological Administration

The CMA AMV algorithm performs well in Experiment 1, detecting the correct displacement of the artificially moved features in all cases, but the AMV comparison to rawinsondes and the NWP background winds exhibit larger errors than other centers in the other experiments. This may have been due to a very extensive use of IR-only T_{BT} in determining AMV heights.

EUMETSAT

The strengths of the EUM AMV algorithm are highlighted in Experiment 1 and 4; all vector displacements are correct (Experiment 1) and the statistical comparison of the EUM AMVs to rawinsondes and the background forecast wind field performs best together with NWC AMVs (Experiment 4), with a very dense coverage of AMVs at both high and low levels.
In Experiments 2 and 3 on the other hand, the use of IR-only T_{BT} results in AMVs being placed several hundred hPa different than when other techniques could be used (Experiment 4). This conclusion is confirmed by the high error in the rawinsonde comparison statistics and is likely due to a brightness temperature that is too warm.

Japan Meteorological Agency

The JMA AMV algorithm performs very well in Experiments 2 and 3, but results from Experiment 4 show a relative degradation of validation statistics when measuring performance against both rawinsonde and NWP background winds. Specifically, the AMV coverage for JMA is very dense in low levels, but the upper-level winds are few and do not compare well.

Korea Meteorological Administration

The KMA AMV algorithm performs relatively well in all four Experiments, especially in Experiment 2 and 3. In Experiment 4, AMV coverage is dense for the upper-level winds; however lower-level winds are assigned too high in the atmosphere.

NOAA

The strength of the NOA algorithm lay in its cloud height determination, as evidenced in Experiment 4; a substantial number of heights are adjusted (as compared to IR-only T_{BT}), which result in an improvement in the statistical comparison to rawinsondes and the NWP background winds.

NWC SAF

Among all of the centers in the study, the NWC AMV algorithm has in general the best statistics as compared to rawinsondes and the NWP background winds. Moreover, NWC AMVs with IR-only cloud height performs better than several other centers using other cloud height techniques.
There are two areas noted for suggestion to improve the NWC AMV algorithm: first, investigate increasing the coverage of the upper-level winds since it is less dense than several other centers (e.g., EUM, NOA, KMA) when the prescribed configuration is used. Second, the IR T_{BT} technique used by NWC may not be the best method for warmer clouds as the lower-level clouds are placed too high in Experiment 2.

REFERENCES

Genkova, I., R. Borde, J. Schmetz, J. Daniels, C. Velden, K. Holmlund, 2008: Global atmospheric motion vectors intercomparison study, *9th Int. Winds Workshop*, Annapolis, MD USA, April 2008.

Genkova, I., R. Borde, J. Schmetz, C. Velden, K. Holmlund, N. Bormann, P. Bauer, 2010: Global atmospheric motion vector intercomparison study, *10th Int. Winds Workshop*, Tokyo, Japan, February 2010.

Santek, D., J. García-Pereda, C. Velden, I. Genkova, S. Wanzong, D. Stettner, M. Mindock, 2014: 2014 AMV intercomparison study report. Technical Report available online at: www.nwcsaf.org/HD/files/vsadoc/CIMSS_AMV_Comparison_FinalReport_04July2014.pdf.